Enamel Hypoplasia in Ancestral Puebloan Populations From Southwestern Colorado: I. Permanent Dentition

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ABSTRACT Dental enamel hypoplasias are used to examine metabolic disruption experienced during early childhood by ancestral Puebloan (Anasazi) inhabitants of southwestern Colorado. The hypoplasia sample consists of the permanent anterior dentition from 147 individuals from Montezuma County and Mesa Verde National Park. Using the individual as the basis of analysis, the study compares different time periods of occupation of the region with respect to prevalence and timing of hypoplasia occurrence. The frequency of enamel hypoplasia in the combined regional sample is high, affecting 90% of the individuals and 66% of the anterior teeth. The earliest onset of hypoplasia in individuals occurs most commonly at 2.5–3.0 years, and the peak age for enamel disruption is 3.0–3.5 years. There are no significant differences in hypoplasia frequency or timing between males and females or between adults and subadults. The level of childhood stress appears to have increased significantly with time from the Basketmaker III to the Pueblo I and Pueblo II periods, then decreased slightly during the Pueblo III. The differences between the Pueblo I, II, and III periods are not significant. The Pueblo II sample from Yellow Jacket Canyon sites 5MT1 and 5MT3 and the Dolores Pueblo I sample show the highest levels of childhood stress in comparison to other Puebloan populations inhabiting this region prior to A.D. 1300. Am. J. Phy. Anthropol. 102:351–367, 1997.

This study uses dental enamel defects known as enamel hypoplasias as indicators of systemic physiological stress experienced during early childhood by ancestral Puebloan (Anasazi) individuals from southwestern Colorado. I compare the prevalence and timing of hypoplasia in northern Anasazi individuals who lived at different times. I also examine differences in stress level between contemporaneous prehistoric populations from different archaeological sites in the region.

Enamel hypoplasia as an investigative tool

Enamel hypoplasia is a developmental defect of tooth crown formation resulting from deficient apposition of enamel matrix due to impaired functioning of ameloblasts, the specialized enamel-forming cells (Goodman and Rose, 1990; Skinner and Goodman, 1992). Disrupted enamel formation is a sensitive but nonspecific response to a variety of factors that interfere with metabolism and normal growth. These factors include malnutrition, infectious disease, parasitism, and weaning (Goodman and Rose, 1990).

The first few years of life are a time of rapid growth when nutritional needs are high and infants and children are particularly vulnerable to environmental stressors. There is strong interaction between malnutrition and disease. Poorly nourished children may have reduced resistance to illness, and common childhood illnesses such as diarrhea or respiratory infection can pro-

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duce adverse effects on nutritional status by impairing nutrient adsorption or decreasing appetite. Because dental enamel is durable and does not remodel, hypoplastic defects provide a permanent record in older individuals of systemic physiological stress experienced during early childhood.

Enamel hypoplasia has been shown to correlate with anthropometric indicators of nutritional status such as height, weight, and skinfold thickness, and it is associated with socioeconomic status (Goodman et al., 1988). Long-term studies of undernourished children have provided evidence that chronic nutritional stress is one of the primary causes of enamel hypoplasia and that hypoplasia frequency can be reduced significantly by nutritional supplementation during childhood (Goodman et al., 1989; May et al., 1993). Goodman et al. (1991) showed that nutritional supplementation from birth of Mexican adolescents reduced the hypoplasia frequency from 74.4% in the untreated control group to 39.5% in the supplemented group.

Enamel hypoplasia is common in many Third World populations experiencing chronic nutritional stress. In modern China, for example, hypoplasia frequency has been found to be significantly higher in Chinese born during a period of famine years (57.3%) compared to individuals born after the famine (35.9%; Zhou and Corruccini, 1994). Similarly high hypoplasia frequencies have been reported for several archaeological populations from North America, including 66% for the Dickson Mounds series (Goodman et al., 1980) and 54.5% for a Barbados slave population (Corruccini et al., 1985).

Hypoplasia prevalence appears to be high in Native American populations inhabiting the American Southwest prior to European contact. Among the Black Mesa Anasazi, 85% of the individuals have at least one manifestation of hypoplasia (Nelson et al., 1994). Nearly all age and sex groups at Black Mesa appear to have experienced endemic, mild to moderate nutritional stress (Martin et al., 1991). Other hypoplasia frequencies reported for this region include 55% for the Mesa Verde Anasazi (Stodder, 1987), 8.7% to 21.3% for different skeletal series from the Kayenta Anasazi (Ryan, 1977), and 99% for the Pueblo Grande Hohokam (Karhu et al., 1992). Methodological differences may account in part for the great variation in reported hypoplasia frequencies.

One serious methodological problem encountered with previous methods for estimating timing of stress was that different tooth types appeared to differ in the timing of stress, with incisors showing earlier peak frequencies of surface defect occurrence than canines (Goodman et al., 1980; Goodman and Armelagos, 1985). Timing of stress in an individual depended, therefore, on which teeth were analyzed (Goodman et al., 1980). However, new standards of crown formation compiled by Skinner and Goodman (1992) from several different studies indicate that both the upper and lower canine crowns are completed earlier than had previously been thought. The new standards greatly decrease the difference between incisors and canines in timing of peak defect frequencies, making it possible to combine tooth types in estimating the timing of stress experienced by an individual.

Previous methods also failed to take into account the observation that stressful events occurring during the early stage of tooth formation are not expressed on the crown surface because the initially formed portions of crown enamel are "buried" under later-forming enamel increments (Skinner and Goodman, 1992). Approximately 25% of crown formation time in anterior teeth is not expressed on the tooth surface (Skinner and Anderson, 1991).

Is there evidence for childhood stress in the Pueblo II period in southwestern Colorado?

My research uses enamel hypoplasia to examine the relative adaptive success of

Abbreviations

CEJ	Cemento-enamel junction
I1	Central incisor
I2	Lateral incisor
C	Canine
BMIII	Basketmaker III
PI	Pueblo I
PII	Pueblo II
PIII	Pueblo III
DAP	Dolores Archaeological Project
MVNP	Mesa Verde National Park
YJ	Yellow Jacket

ancestral Puebloan populations who inhabited the extreme southwestern corner of Colorado, a region which includes Mesa Verde and the Dolores and Montezumza River drainages (Fig. 1). The earliest time period represented in the permanent dentition sample is the Basketmaker III period, which is dated to A.D. 500 to 700 in the Pecos Classification (Kidder, 1927), but which did not begin in southwestern Colorado until about A.D. 600 (Berry, 1982).

The ancestral Puebloan inhabitants of the region were horticulturalists who cultivated maize, beans, and squash, supplementing their diet with weedy annuals such as amaranth and chenopodium, edible native plants, pinon nuts, and various large and small fauna. The "Four Corners" area (where the states of Colorado, Utah, Arizona, and New Mexico have a common boundary today) has always been plagued by unpredictable precipitation and short growing seasons that create difficult and uncertain conditions for agriculture. One of the initial adaptive strategies by which the early ancestral Puebloan inhabitants of this region responded to crop failure and depletion of wild resources was through "population relocation and movement between environmentally diverse areas" (Schlanger, 1988:773). As population density increased in the area, making relocation more difficult, intensification of agricultural methods was another adaptive response.

A previous study of enamel hypoplasia in individuals buried at Yellow Jacket Canyon sites 5MT1 and 5MT3 found significantly more hypoplasia in Pueblo II permanent dentition than in Pueblo III teeth from these same sites (Malville, 1994), an indication that the earlier occupants of 5MT1 and 5MT3 experienced greater childhood stress than the later inhabitants. One purpose for undertaking the present regional study was to determine whether any other Pueblo II population from the Mesa Verde area experienced similarly high levels of stress during childhood. If so, this might be an indication of region-wide climatic instability during the Pueblo II period that caused unreliable crop production and food shortages. On the other hand, if there is no evidence of increased stress in any other Pueblo II population from this region, other explanations must be sought for the significantly higher stress levels found in Pueblo II burials from sites 5MT1 and 5MT3.

TABLE 1. Composition of the hypoplasia sample

Archaeological site	Time period					Total
	BMIII[1]	PI	PII	PIII	Unknown	
DAP	2	17	1	2		22
Duckfoot Pueblo		10				10
MVNP	3	6	17	26	1	53
YJ 5MT1/5MT3	3		16	18		37
Other sites[2]		3		17	5	25
Combined sample	8	36	34	63	6	147

[1] Abbreviations: BMIII, Basketmaker III (A.D. 500–700); PI, Pueblo I (A.D. 700–900); PII, Pueblo II (A.D. 900–1100); PIII, Pueblo III (A.D. 1100–1300); DAP, Dolores Archaeological Project; MVNP, Mesa Verde National Park; YJ, Yellow Jacket.
[2] Sand Canyon Pueblo, Wallace Ruin, Mockingbird Mesa, and private land in Yellow Jacket Canyon area.

MATERIALS AND METHODS

The permanent dentition sample consists of the dental remains of 147 ancestral Puebloan individuals from Montezuma County and Mesa Verde National Park (Table 1). The following Montezuma County archaeological sites are included in the sample (Fig. 1): Yellow Jacket Canyon area sites 5MT1 and 5MT3 (Wheat, 1983; Lange et al., 1986; Malville, 1994); Duckfoot Pueblo, 5MT3868 (Hoffman, 1993); Sand Canyon Pueblo, 5MT765 (Hoffman, 1990; Bradley, 1992); Wallace Ruin, 5MT6970 (Bradley, 1988); the Dolores Archaeological Program (DAP) (Stodder, 1987); and Mocking Bird Mesa (Fetterman and Honeycutt, 1987). The various sites represented in the Mesa Verde National Park (MVNP) sample are listed in Table 2. The majority of MVNP burials come from more recent excavations of Pueblo II and Pueblo III sites on Wetherill Mesa, but some earlier Chapin Mesa sites are also included (Bennett, 1975; Hayes and Lancaster, 1975; Rohn, 1971, 1977; Swannack, 1969).

The hypoplasia sample includes the following time periods, assigned according to Kidder's Pecos Classification (Kidder, 1927; Bennett, 1975; Berry, 1982): Basketmaker III (A.D. 500 to 700), 8 individuals; Pueblo I (A.D. 700 to 900), 36; Pueblo II (A.D. 900 to 1100), 34; Pueblo III (A.D. 1100 to 1300), 63; time period unknown, 6.

The state of preservation of burials included in the regional study varies greatly,

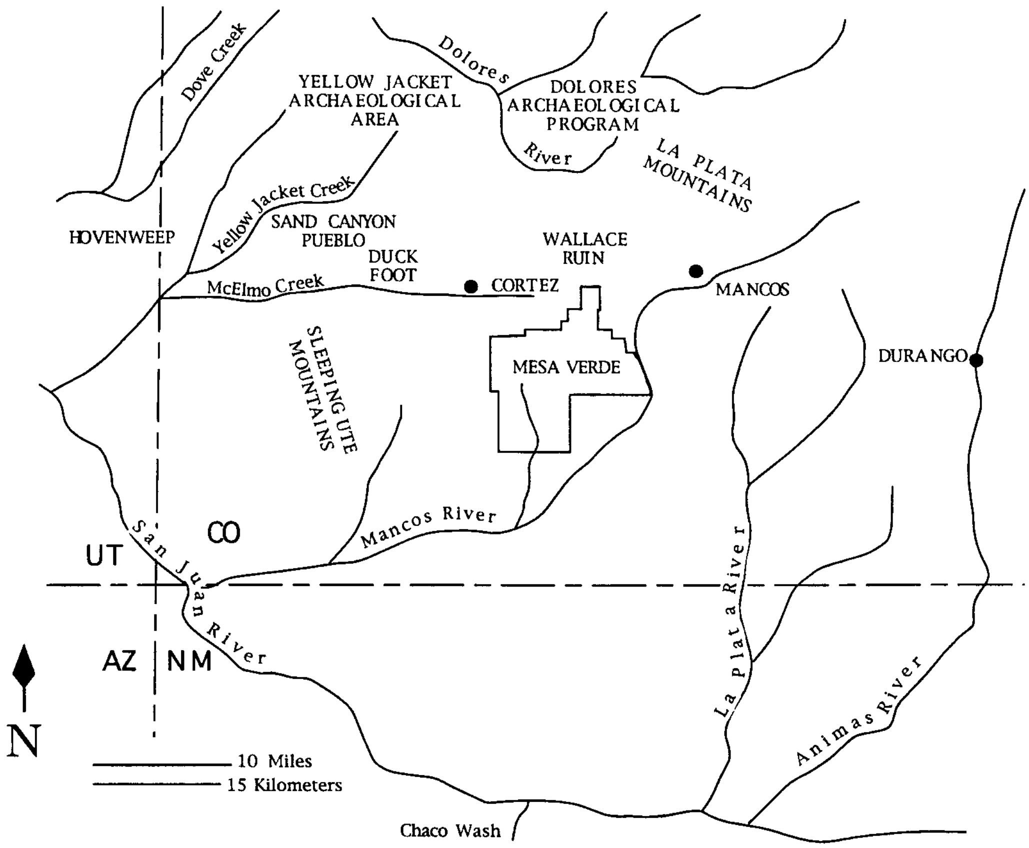

Fig. 1. Map of southwestern Colorado showing location of archaeological sites represented in the hypoplasia sample.

TABLE 2. Mesa Verde National Park sites represented in the MVNP hypoplasia sample

MVNP[1] site		Time period: BMIII	PI	PII	PIII	Unknown	Total
5MV34	Soda Canyon				4		4
5MV820	Coyote House				2		2
5MV1200	Long House				10		10
5MV1228	Adobe Cave				2		2
5MV1229	Mug House			2	4		6
5MV1241	(cave site)			1			1
5MV1253				1			1
5MV1452	Badger House			5	3		8
5MV1595	Big Juniper House			3	1		4
5MV1645	Two Raven House			4			4
5MV1676	Badger House Community		5				5
Chapin Mesa sites 5MV16, 60, 145, 744, & 1025		3	1	1		1	6
Combined sample		3	6	17	26	1	53

[1] For the meaning of abbreviations, see Table 1.

ranging from a few well-preserved burials with nearly complete dentition and good representation of skeletal elements to other burials of which little remains but a few teeth and skeletal fragments. Many of the teeth present were unusable because of severe wear or broken enamel. Only teeth with completed crown development that were suf-

ficiently well preserved to permit examination of the enamel surface were included in the sample. The exclusion of badly worn teeth eliminated individuals older than about 40 years, biasing the sample towards younger individuals.

Six different anterior tooth types were examined: the maxillary and mandibular incisors, both central and lateral, and the canines, giving a combined total of 1,041 permanent teeth. Enamel attrition was scored on an eight-point scale, with the limit for maximum allowable wear set at Smith stage 5, defined as showing a "large dentin area with rim complete" (Smith, 1984:45). The mean wear score for the entire sample of teeth is 2.2 ± 1.1, corresponding to only minor exposure of dentin.

The enamel surface was examined under low magnification and oblique light using a $3\times$ power Optivisor, but only those surface defects visible without magnification that appeared to be associated with depression in the enamel surface were recorded. Defects were scored according to the FDI guidelines (Fédération Dentaire International, 1982) as being either pits (FDI type 3), horizontal grooves (FDI type 4), or a combination of hypoplastic defects. The term enamel hypoplasia is used here to refer to a half-year interval showing "any deficiency of enamel thickness, including a pit, line, groove, or other form of missing enamel of various depths" (Skinner and Goodman, 1992:157). Although hypocalcification defects such as opaque or discolored enamel were frequently observed in the sample and were noted during the examination, these types of defective enamel are not discussed in the present study.

No destructive testing was involved in the analysis. Fine-tipped Helios dial calipers were used to measure crown height and the distance of defects from the center of the defect to the cemento-enamel junction [CEJ]. In the case of more extensive regions of malformed enamel, the positions of both the upper and lower boundaries of the defect were recorded. Hypoplasia measurements were converted to percent of crown height, using individual crown heights for unworn teeth or sample mean crown heights for teeth with stage 3 or greater wear.

This study uses the individual as the unit of analysis. Only individuals with at least three usable anterior teeth present (or two anterior teeth with chronologically matched defects) were included. Surface defects appearing during the same half-year interval on two or more anterior teeth from a given individual were considered to indicate systemic stress experienced during that period of crown enamel formation. Defects not matched chronologically across at least two teeth from that individual were excluded from consideration because of the possibility that enamel hypoplasia of one tooth only might be caused by local inflammation or trauma rather than by systemic disturbances (Spouge, 1973; Suckling, 1989). For some individuals, this conservative approach underestimates by 0.5 to 1.0 years the total length of time of enamel disruption. An individual was considered to be free of defects only if at least three anterior permanent teeth from that individual were available for examination. This "defect-free" category includes six individuals totally free of hypoplasia as well as nine individuals with minor hypoplasia on only one tooth.

The approximate age of the individual at the time of formation of each hypoplasia was estimated from the location of the defect on the crown surface using the mineralization diagram shown in Figure 2, which I developed from data compiled by Skinner and Goodman (1992). This diagram also takes into account the problem of "buried" enamel discussed by Skinner and Goodman (1992).

Significance of the difference between means was assessed by both the *t*-test and the nonparametric Mann-Whitney *U* test (Siegel, 1956), but only the more conservative probabilities (two-tailed) of the Mann-Whitney *U* test are given.

RESULTS

Types of hypoplasia

The prevalence of enamel hypoplasia in the regional sample is high. Ninety percent of the individuals (132/147) show hypoplastic defects occurring during the same half-year growth interval on at least two anterior teeth, and 66% of the anterior teeth examined (689/1,041) are affected. In cases where nearly complete anterior dentition is avail-

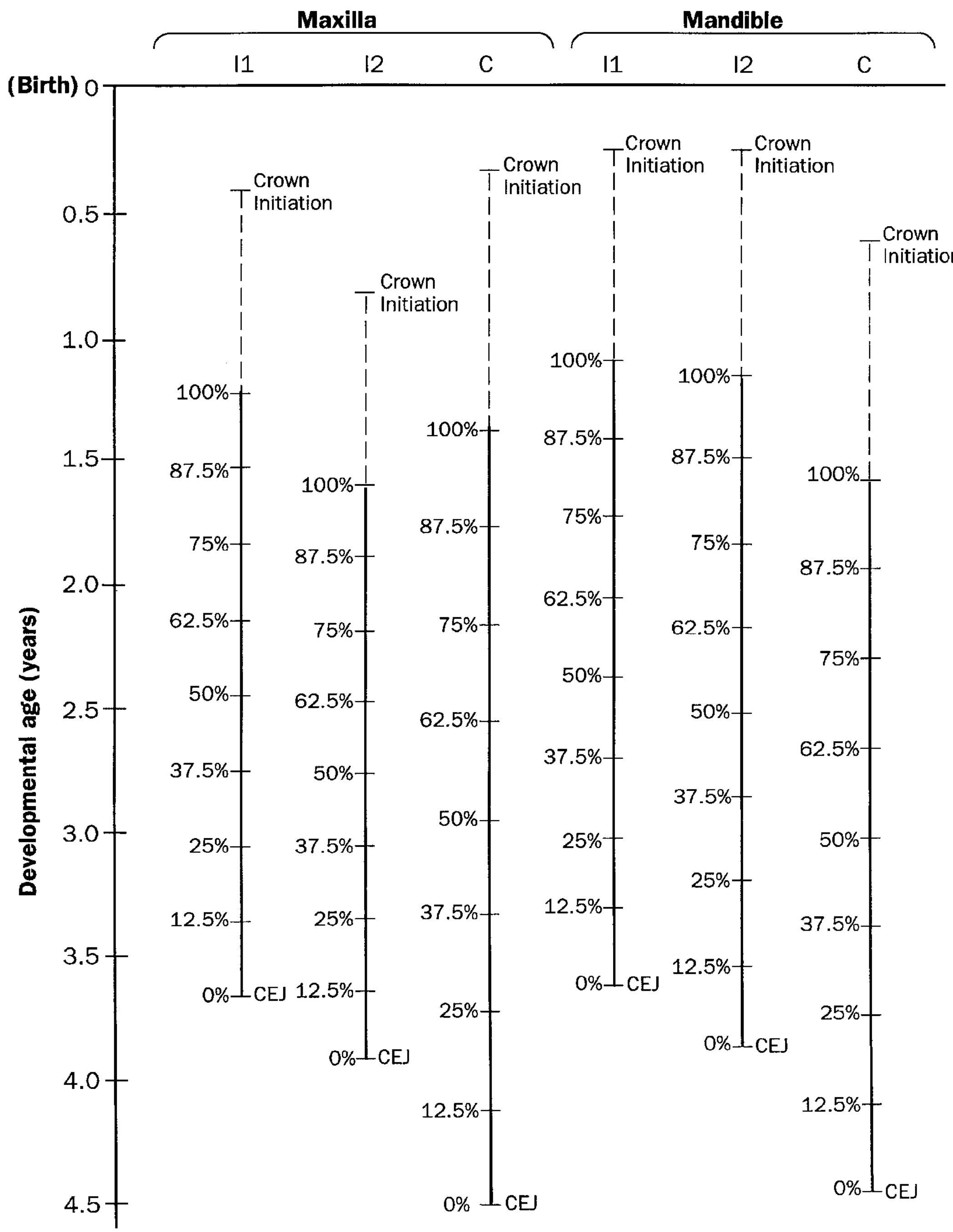

Fig. 2. Mineralization diagram for the human permanent anterior dentition. Malville developed the diagram from data compiled by Skinner and Goodman (1992) for age of onset and completion of enamel deposition. Dotted lines indicate "buried enamel" and solid lines indicate enamel visible on crown surface.

able for an individual, some defects can be matched chronologically across 10 to 12 teeth. This analytical approach using only matched defects should be regarded as a conservative minimum estimate of growth disruption, however, because the anterior dentition is incomplete for many individuals. Availability of a more complete dentition

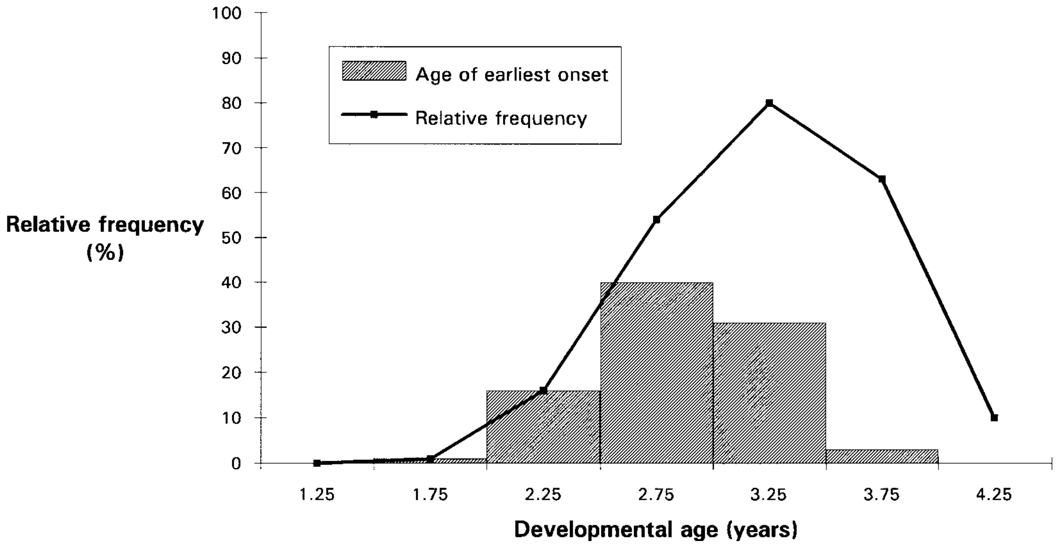

Fig. 3. Comparison of age of earliest onset of dental enamel hypoplasia (columns) with relative hypoplasia frequency (solid line).

would clearly increase the number of defects that could be matched across two or more teeth for each individual.

While the prevalence of enamel hypoplasia is high, the degree of disruption is mild in most cases. The types of hypoplastic defects observed in the regional sample are similar to those reported previously for the Yellow Jacket permanent dentition sample (Malville, 1994). Horizontal grooves or shallow horizontal depressions (FDI Type 4) are the most common type of hypoplasia, accounting for most of the surface defects on incisors. The next most frequently observed type of hypoplasia resembles the "pit patch" areas that Goodman et al. (1992) suggest may indicate episodes of chronic metabolic stress. This type of disrupted enamel occurs more commonly on canines than on incisors. Pitting (FDI Type 3) is not common on either tooth type, but is observed more frequently on incisors than on canines. Various defect combinations occur together occasionally, for example, rows of pits or discrete linear defects located within wider regions of depressed or malformed enamel.

Timing of systemic stress

Earliest onset of hypoplasia in the regional sample occurs most commonly at about 2.5 to 3.0 years, ranging from 1.5 to 4.0 years of age (Fig. 3). The peak age of defect occurrence is 3.0 to 3.5 years (Fig. 3), at which age 80% of the individuals in the combined sample show at least minor hypoplasia on two or more teeth. The apparent decline in hypoplasia frequency after 3.5 years may be due more to the fact that fewer teeth are still forming new enamel after this age rather than to a decrease in the level of stress.

For the combined sample the average length of time during which individuals show evidence of enamel disruption is approximately one year, i.e., 2.2 half-year intervals (Table 3). Some individuals, however, show continuous disruption of enamel from 2.0 to 4.5 years of age, at which time the anterior teeth no longer produce new enamel. The extensive regions of malformed enamel or "pit patches" noted on many canines may indicate long periods of chronic metabolic stress with little intervening opportunity for recovery.

Influence of age and sex on hypoplasia formation

Division of the sample on the basis of age and sex does not reveal any significant differences between males and females or between adults and subadults in either timing or frequency of hypoplasia occurrence (Table

TABLE 3. Diachronic comparison of prehistoric Puebloan individuals from southwestern Colorado

Group	N	Avail. teeth/indiv. Mean (S.D.)	Percentage of affected teeth	Percentage of affected individuals[2]	Duration of disruption[3] Mean (S.D.)
BMIII[1]	8	5.9 (2.8)	34	75	1.3 (1.0)
All PI	36	8.1 (3.2)	67	94	2.5 (1.2)
DAP PI	17	9.0 (2.5)	71	94	2.9 (1.2)
Other PI[4]	19	7.3 (3.5)	62	95	2.1 (1.1)
All PII	34	7.9 (3.2)	72	94	2.8 (1.2)
MVNP PII	18	7.1 (3.1)	66	84	2.3 (1.3)
YJ PII	16	8.9 (3.1)	80	100	3.3 (0.9)
All PIII	63	6.2 (2.9)	68	86	2.0 (1.2)
MVNP PIII	26	5.6 (2.5)	71	81	1.8 (1.2)
YJ PIII	18	7.2 (2.9)	61	83	1.8 (1.3)
Other PIII[5]	19	6.1 (3.1)	70	95	2.3 (1.2)
Combined	141	7.1 (3.2)	66	90	2.2 (1.3)

[1] Abbreviations: BMIII, Basketmaker III; PI, Pueblo I; PII, Pueblo II; PIII, Pueblo III; DAP, Dolores Archaeological Project; MVNP, Mesa Verde National Park; YJ, Yellow Jacket.
[2] Percentage of individuals with at least one defect matched chronologically on two anterior teeth.
[3] Number of affected half-year intervals per individual.
[4] Duckfoot, MVNP, YJ area.
[5] Sand Canyon, Wallace, and DAP.

TABLE 4. Influence of age and sex on hypoplasia formation

Group	N	Avail. teeth/ indiv. Mean (S.D.)	Percent-age of affected teeth	Percentage of affected individuals[1]	Duration of dis-ruption[2] Mean (S.D.)
Males	44	7.5 (3.3)	66.7	93	2.4 (1.3)
Females	50	7.1 (3.1)	66.2	88	2.3 (1.2)
Subadults	45	7.0 (3.2)	64.3	87	2.0 (3.3)

[1] Percentage of individuals with at least one defect matched chronologically on two anterior teeth.
[2] Number of affected half-year intervals per individual.

4). The three groups (i.e., males, females, and subadults) appear to be closely matched with respect to percentage of affected teeth, percentage of affected individuals, average duration of enamel disruption per individual, and also in relative frequency and timing of defects (Fig. 4).

Diachronic comparison

Separation of the southwestern Colorado regional sample into its component groups discloses significant differences between time periods and geographical locations with respect to hypoplasia prevalence and duration of enamel disruption (Table 3). The peak age of hypoplasia occurrence, however, remains constant at 3.0 to 3.5 years throughout all time periods.

The Basketmaker III sample shows the least evidence of childhood stress, with 50% of the individuals showing defects at 3.0–3.5 years (Fig. 5). It is inadvisable to draw any definite conclusions about this time period, however, because of the small sample size. The onset of earliest hypoplasia begins at a later age in Basketmaker III individuals than in individuals from other time periods, and the average duration of enamel disruption (1.3 half-year intervals or 0.65 years) is shortest also in the Basketmaker III group (Table 3 and Fig. 6).

During the Pueblo I period in southwestern Colorado, the level of early childhood stress appears to have increased in comparison to the earlier Basketmaker III period (Table 3 and Fig. 6). The mean duration of enamel disruption (1.25 years) for the com-

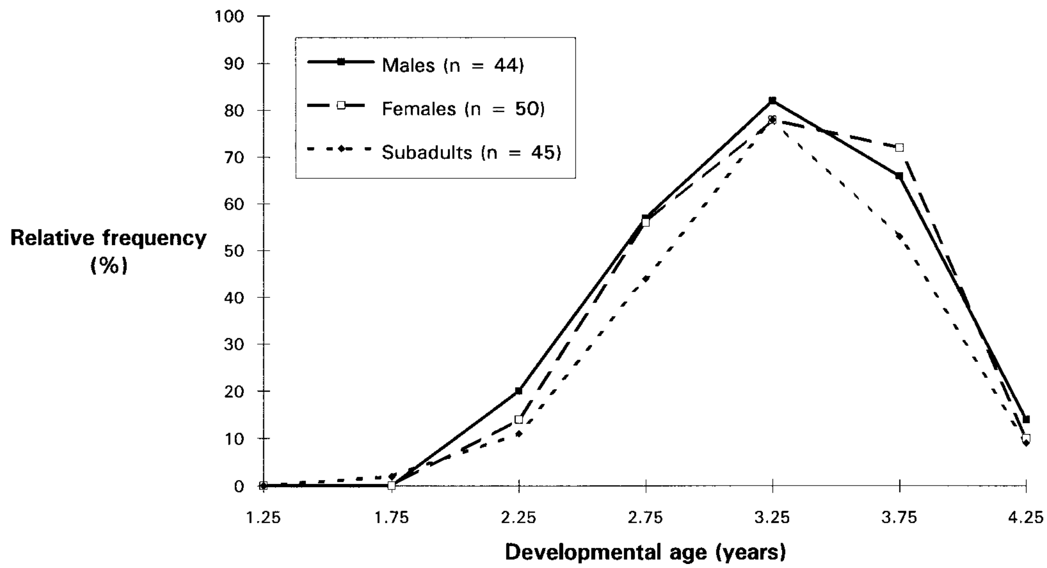

Fig. 4. Comparison of relative frequency of enamel hypoplasia for males, females, and subadults in combined regional sample.

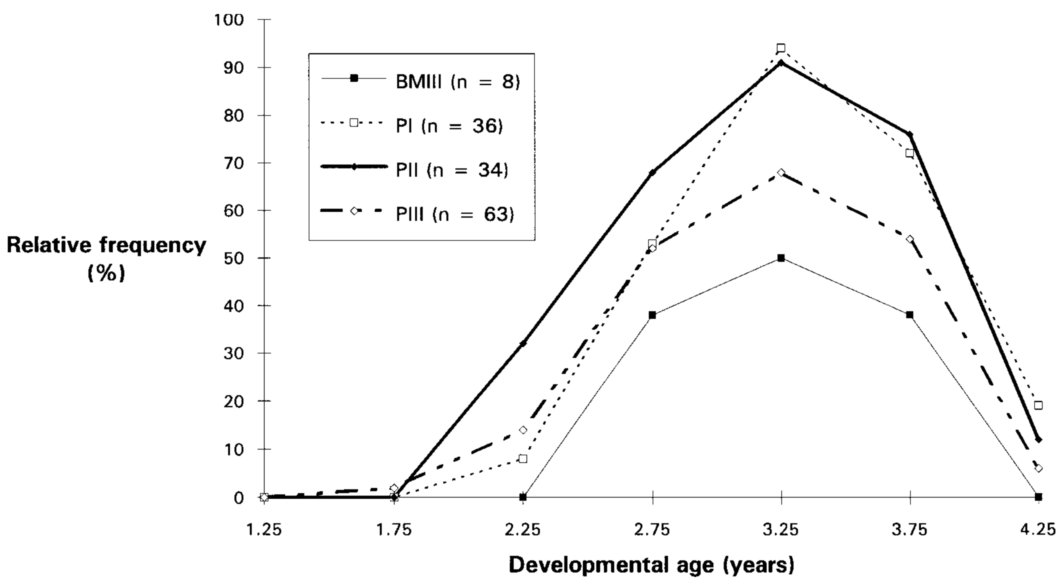

Fig. 5. Diachronic comparison of relative frequency of enamel hypoplasia in combined regional sample.

bined Pueblo I sample is significantly longer than the Basketmaker III mean of 0.65 years ($P < 0.05$). Nearly all of the Pueblo I individuals (94%) show evidence of disrupted enamel formation during the 3.0–3.5 year interval in comparison to 50% among the Basketmaker III group (Fig. 5). Pueblo I teeth from Dolores show longer duration of enamel disruption than teeth from other Pueblo I sites (Fig. 6).

The Pueblo II sample, which includes both Mesa Verde and Yellow Jacket 5MT1/5MT3, shows the greatest evidence of growth disruption. Onset of earliest hypoplasia forma-

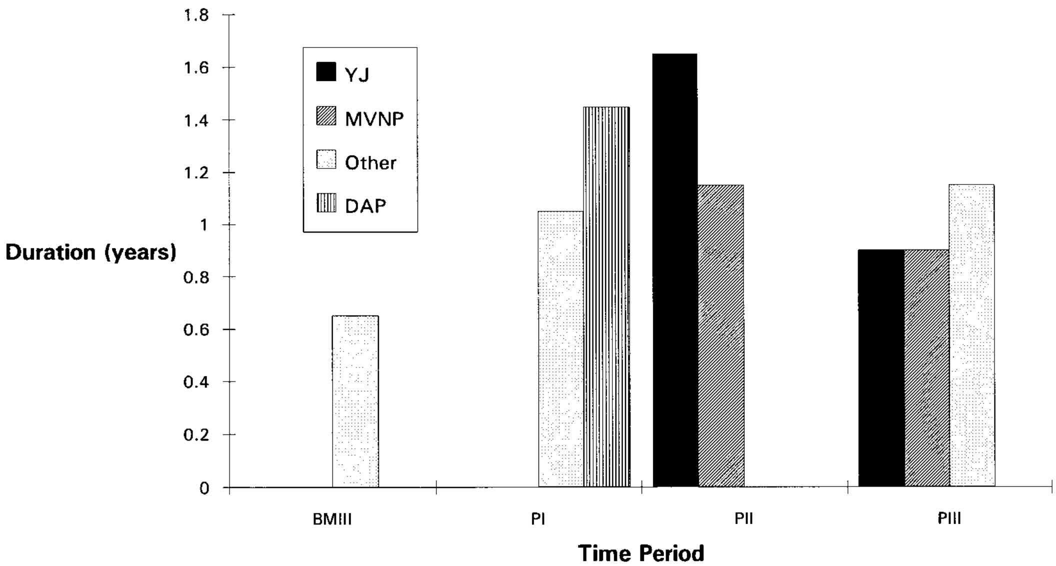

Fig. 6. Diachronic comparison of duration of enamel disruption during early childhood in combined regional sample.

tion begins at an earlier age for Pueblo II individuals (Fig. 5) and the mean duration of enamel disruption is significantly longer ($P < 0.01$) for Pueblo II individuals than for Basketmaker III or Pueblo III (Table 3). At the peak age of hypoplasia occurrence, 3.0–3.5 years, 91% of the Pueblo II individuals show enamel disruption.

Further separation of the Pueblo II sample into its Mesa Verde and Yellow Jacket 5MT1/5MT3 components shows that although both Pueblo II groups show somewhat earlier onset of hypoplasia than teeth from other time periods, the overall level of stress appears to have been greater at Yellow Jacket Canyon sites 5MT1/5MT3 than at Mesa Verde (Table 3 and Figs. 6 and 7). Pueblo II burials from 5MT1/5MT3 show significantly longer duration of enamel disruption per individual ($P < 0.05$) than Pueblo II burials from Mesa Verde, and 100% of the Yellow Jacket individuals show enamel defects at the peak age of hypoplasia occurrence compared to 84% of the Mesa Verde Pueblo II individuals.

During the Pueblo III period, the stress level experienced during early childhood in southwestern Colorado appears to have decreased in comparison with Pueblo I and Pueblo II values for this region (Table 3), with 68% of the individuals showing defects at 3.0–3.5 years, the peak age for hypoplasia formation (Fig. 5). There are no significant differences in hypoplasia values between the different Pueblo III populations represented in the regional sample, although duration of enamel disruption is slightly longer in Sand Canyon and Wallace teeth (1.1 years) than in either Mesa Verde or Yellow Jacket 5MT1/5MT3 teeth (0.9 years, Fig. 6). Sand Canyon and Wallace burials are dated to the late Pueblo III period, the time period immediately preceding final abandonment of the region, whereas those from Mesa Verde and Yellow Jacket represent a longer time period spanning the entire PIII occupation of the region.

Comparison of the Yellow Jacket Pueblo II sample with other populations in the regional sample shows that Pueblo II individuals from 5MT1/5MT3 have the highest percentage of affected teeth, the longest duration of enamel disruption, and the highest prevalence of hypoplasia (100%) of all the regional populations examined (Table 3). The duration of disruption is significantly longer ($P < 0.01$) in the Pueblo II sample from 5MT1/5MT3 compared to the Pueblo III period at these Yellow Jacket Canyon sites (Table 3 and Fig. 8).

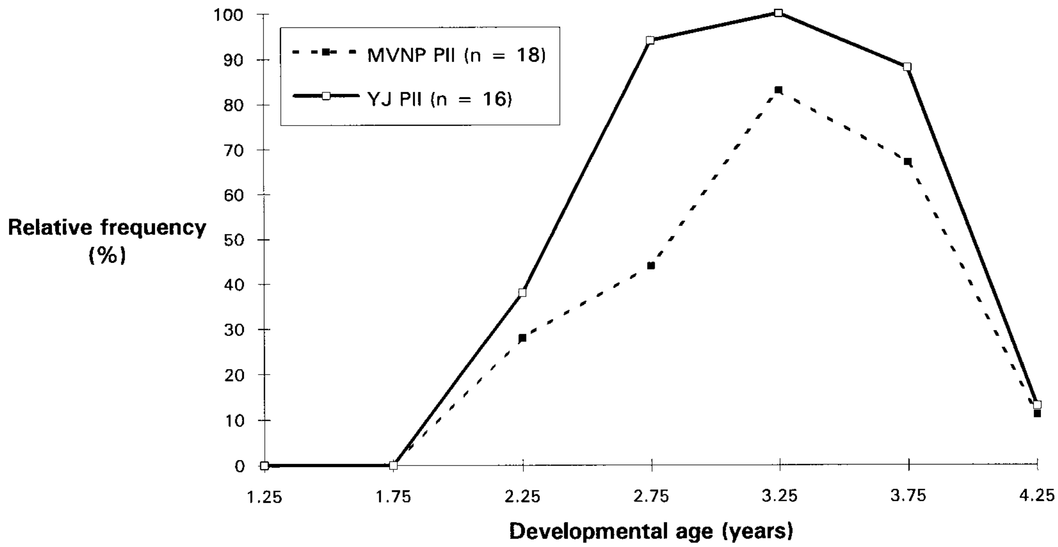

Fig. 7. Comparison of relative frequency of enamel hypoplasia in Pueblo II individuals from Mesa Verde and Yellow Jacket Canyon sites 5MT1 and 5MT3. MVNP PII, Mesa Verde National Park Pueblo II period; YJ PII, Yellow Jacket Pueblo II period.

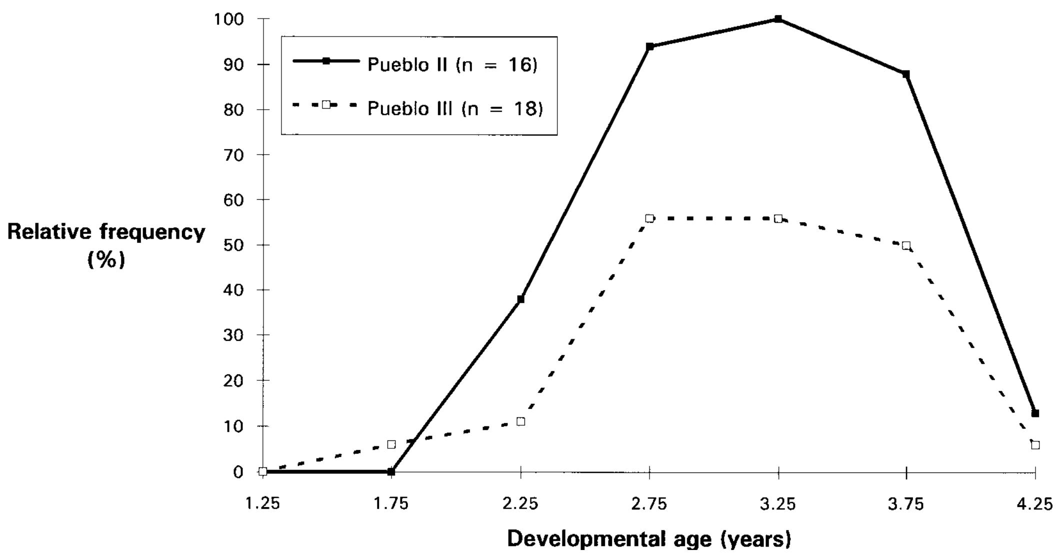

Fig. 8. Diachronic comparison of relative frequency of enamel hypoplasia in Pueblo II and Pueblo III individuals from Yellow Jacket Canyon sites 5MT1 and 5MT3.

Additional evidence of growth disruption in the Yellow Jacket Pueblo II population from 5MT1/5MT3 is provided by comparing Yellow Jacket adult long bone measurements with values reported for other ancestral Puebloan skeletal series. Pueblo II long bones from 5MT1/5MT3 males (Table 5) are shorter and less robust, on the average, than those from Mesa Verde (Bennett, 1975), Dolores (Stodder, 1987), Duckfoot (Hoffman, 1993), Black Mesa (Martin et al., 1991), and Pecos (Hooton, 1930). Measurements for the Pueblo II 5MT1/5MT3 males are typically about one standard deviation below those

TABLE 5. Postcranial measurements in adult males from various Anasazi skeletal series

Long bone measurements (cm)	YJ 5MT1/5MT3[1] PII n Mean (S.D.)	PIII n Mean (S.D.)	Mesa Verde[2] n Mean (S.D.)	Dolores[3] n Mean (S.D.)	Duckfoot[4] n Mean (S.D.)	Black Mesa[5] n Mean (S.D.)	Pecos[6] (L side) n Mean (S.D.)
Humerus maximum length	4	2	17	9	3	18	134
	29.70	30.45	30.75	30.54	30.47	30.59	30.82
	(1.04)	(1.65)	(1.19)	(1.29)	(0.86)	(1.12)	(1.47)
Femur maximum length	5	3	17	9	2	15	140
	41.52	43.43	43.18	42.52	43.00	42.91	42.67
	(1.42)	(1.50)	(1.66)	(2.12)	(0.10)	(1.78)	(1.98)
Femur maximum head diameter	4	3	14	12	4	21	154
	4.04	4.41	4.28	4.81	4.32	4.29	4.29
	(0.16)	(0.15)	(0.21)	(0.41)	(0.23)	(0.25)	(0.26)
Femur A-P midshaft diameter	6	5	19	8	3	32	156
	2.31	2.71	2.71	2.81	2.77	2.68	2.81
	(0.25)	(0.18)	(0.23)	(0.58)	(0.17)	(0.21)	(0.25)
Femur M-L midshaft diameter	6	5	19	8	3	32	156
	2.33	2.34	2.36	2.80	2.37	2.58	2.44
	(0.19)	(0.15)	(0.22)	(0.44)	(0.09)	(0.26)	(0.20)
Tibia length	6	2	18	7	3	16	117
	33.83	35.55	36.35	35.56	35.63	36.57	35.78
	(1.29)	(1.65)	(1.47)	(1.17)	(0.46)	(1.72)	(1.87)
Tibia A-P dia. at nutr. foramen	6	4	23	10	3	28	144
	3.18	3.58	3.48	3.78	3.73	3.42	3.55
	(0.24)	(0.20)	(0.28)	(0.50)	(0.05)	(0.27)	(0.31)
Tibia M-L dia. at nutr. foramen	6	4	23	9	3	27	143
	1.97	2.19	2.13	2.66	2.2	2.24	2.16
	(0.10)	(0.04)	(0.22)	(0.44)	(0.37)	(0.20)	(0.22)

[1] Swedlund (1969): Malville, present study.
[2] Bennett (1975).
[3] Stodder (1987).
[4] Hoffman (1993).
[5] Martin et al. (1991).
[6] Hooton (1930).

for Pueblo III males from 5MT1/5MT3 and for other Anasazi males.

DISCUSSION

Timing of enamel disruption

The present study of hypoplasia in permanent teeth differs from previous published studies in two major ways. First, it introduces a new method for estimating the timing of enamel disruption based on the most recent understanding of crown enamel development (Skinner and Goodman, 1992), and second, it uses the individual as the unit of analysis. Even though the timing of episodes of metabolic disruption may vary from one person to another, teeth from a given individual should, in theory, show similar timing of surface defect occurrence provided that new enamel is being formed during that period. As Figure 2 shows, there is a period of roughly 2 years, from 1.4 to 3.6 years of age, when all anterior crowns are forming new surface enamel and have the potential to record stressful events in the form of surface defects matched across all anterior teeth.

Timing of earliest onset of hypoplasia formation was found to be identical in both the incisors and the canines in nearly three-quarters (71%) of the 94 hypoplastic individuals for whom both incisors and canines are available. In another 26% of the individuals, the incisors show earlier onset of defects than the canines, and canines precede incisors in 3%. The close agreement between incisor and canine timing observed in the majority of individuals suggests that the mineralization diagram in Figure 2 offers an acceptable new approach for estimating the approximate timing of hypoplasia formation in individuals. Future advances in the knowledge of crown enamel development should permit further refinement of the mineralization diagram.

The constant rate of enamel deposition indicated in Figure 2 is actually an oversim-

plification because Liversidge et al. (1993) have shown that the rate of enamel formation is not linear but gradually decreases with time. Taking this rate change into account would have a greater effect on later-forming, more cervically located defects and should bring timing of canine defects into closer agreement with incisor defects.

A note of caution regarding the interpretation of hypoplasia measurements is necessary. Although the term "duration of disruption" is used in this study to indicate the width of the disturbed enamel band and is reported in terms of approximate chronological ages, the actual relationship between the duration and severity of the metabolic disturbance and the resulting region of disturbed enamel is uncertain. Experimental studies by Suckling (1989) on sheep incisors have shown that a single systemic disturbance can produce considerable variation in width of hypoplastic band and extent of missing enamel.

Rates of tooth development may have been somewhat different in the present Northern Anasazi sample than in the populations on whom the tooth development standards were based. However, use of a common standard to compare the different archaeological populations against each other can provide meaningful information because it is likely that these ancestral Puebloan populations from southwestern Colorado were closely related genetically and probably did not differ appreciably with respect to rates of crown completion or susceptibility to enamel hypoplasia.

Factors contributing to disrupted enamel formation

Chronic protein-calorie undernutrition, acting in combination with infectious disease and parasitic infections, is likely to have contributed to stress and growth disruption in Anasazi children of the Mesa Verde region (Stodder, 1987), as well as at Black Mesa in Arizona (Martin et al., 1991) and Arroyo Hondo Pueblo in New Mexico (Palkovich, 1980; Wetterstrom, 1986). Middle ear infection was a common problem for Black Mesa Anasazi children under 4 years of age, judging from the high rate of infectious lesions found on the temporal and mastoid bones of this age group (Martin et al., 1991). Among the Arroyo Hondo Anasazi, children in the 1.0–4.9 year age group showed a higher frequency of four skeletal pathologies clinically associated with malnutrition and iron deficiency anemia (Palkovich, 1980). Active or healed lesions of cribra orbitalia at Dolores and Mesa Verde (Stodder, 1987) and Black Mesa (Martin et al., 1991) indicate the presence of mild iron deficiency anemia in these populations also.

Parasitic infections would contribute to nutritional deprivation, which may have contributed to hypoplasia formation in early inhabitants of the Mesa Verde region (Suckling et al., 1983). Analyses of fecal remains from the Mesa Verde area (Samuel, 1965; Fry and Hall, 1975; Stiger, 1977) and other Anasazi sites (Fry, 1976; Reinhard, 1988) indicate the presence of tapeworm, roundworm, pinworm, and other helminths in the Four Corners area. In addition, amoeba and giardia may have affected some inhabitants (Stodder, 1987). Increased population density and poor sanitation practices would have increased the opportunities for transmission of infectious diseases and parasitic infection. During the winter months, cold temperatures and periods of heavy snowfall undoubtedly contributed to the general level of stress.

Although genetic factors are known to affect susceptibility to environmental stressors such as malnutrition and disease, genetic differences would seem to be of minor importance in considering hypoplasia formation in southwestern Colorado. A minimum degree of genetic variation would be predicted for the regional hypoplasia sample because of the close geographical proximity of the different archaological sites (Fig. 1) and because the regional groups shared a common cultural tradition.

Diachronic comparison of stress

Pueblo I burials, particularly the Dolores sample, show increased duration of enamel disruption compared to the earlier Basketmaker III sample. Kohler (1990) suggests that the increase in population density in the Dolores area during the A.D. 800s, agricultural intensification, and depletion of wild resources may have resulted in limited avail-

ability of efficient protein sources and may have contributed to increased stress from chronic undernutrition in the Dolores population prior to the abandonment of the area in the late A.D. 800s. Nelson et al. (1994:62) comment that "periodic crop failures were probably more threatening to aggregated populations than to dispersed ones, because of the absence of backup strategies based on mobility or the use of local wild resources."

On the other hand, the hypoplasia data show no indication of a gradual increase through time in biological disruption prior to final abandonment of the Four Corners area by the ancestral Puebloans by A.D. 1300. The Pueblo III period shows slightly less evidence of childhood stress than either the Pueblo I or Pueblo II periods in this region (Table 3 and Fig. 6), but the differences are not significant. The Pueblo III samples do not differ significantly from each other or from the combined regional sample for all time periods, although the Sand Canyon and Wallace teeth, which date to the late Pueblo III period, show slightly longer duration of enamel disruption than the Mesa Verde or Yellow Jacket teeth.

It is possible that environmental conditions may have deteriorated greatly during the final years of Pueblo III occupation of the region prior to A.D. 1300, causing major episodes of food shortage and biological disruption that are not evident in the enamel hypoplasia record. Some individuals could have been so severely stressed during early childhood by malnutrition or disease that they did not survive long enough to erupt permanent teeth. Others who were growing up at this time may have migrated out of the area, not leaving their teeth behind. In either case, these individuals would not be represented in the permanent dentition sample.

Increased stress in Pueblo II burials from Yellow Jacket Canyon sites 5MT1 and 5MT3

It is unlikely that the significantly higher stress levels found in the Pueblo II burials from Yellow Jacket habitation sites 5MT1/5MT3 can be attributed to environmental stressors such as region-wide droughts or crop failures. There is no indication of increased hypoplasia frequency during this time period in the Mesa Verde sample, the only other Pueblo II population from the area available for study. It is possible, but unlikely, that the Yellow Jacket Canyon area sometimes experienced highly localized food shortages caused by severe droughts or killing frosts that did not affect the Mesa Verde.

Social factors may have contributed to the higher level of biological stress noted in the Pueblo II burials from Yellow Jacket. In the first place, the Pueblo II burial sample may not be fully representative of the 5MT1/5MT3 population if more favored members of these habitation sites were buried elsewhere, such as in the nearby large Yellow Jacket Ruin (5MT5), which has not yet been excavated scientifically (Lange et al., 1986; Malville, 1994).

The possibility of social inequality during the Pueblo II period should be considered, such as between the occupants of 5MT5 and the other settlements in the Yellow Jacket Canyon area (Malville, 1994). Kohler (1992: 631) has interpreted the construction of field houses in the Dolores area at the end of the 800s as an attempt by the more privileged households or lineages to monopolize the better field locations. He suggests that if the Dolores area had not been abandoned, this practice "might have eventually led to increased social inequality as wealth differences, based on differential agricultural production, accumulated across generations."

The archaeological record at Yellow Jacket area shows Basketmaker III occupation, followed by a hiatus during the Pueblo I period and reoccupation again during Pueblo II times (Lange et al., 1986). Some families who left the Dolores area at the end of the Pueblo I period may have relocated to nearby Yellow Jacket Canyon, only 5–8 miles distant. Those who settled at the main ceremonial center 5MT5 may have attempted to control the fields and forests in their vicinity. If the Pueblo II inhabitants of nearby habitation sites 5MT1 and 5MT3 were denied access to arable land and local wild resources by more powerful neighbors, they could have experienced chronic protein and energy malnutrition. More severe food shortages may have occurred from time to time if crop yields were poor for several years in

succession and stored food supplies were exhausted.

Faunal remains excavated during the 1988–1990 field seasons (Malville, 1990) from the midden associated with House II at 5MT3 suggest that the Pueblo II inhabitants of this site obtained most of their animal protein through garden-hunting and domestication of turkeys. Animal bone fragments believed to represent food remains, often found in association with ash deposits in the midden, consist primarily of bird (probably turkey) and small and very small mammals. No artiodactyl food remains are represented in the faunal assemblage from House II midden, in contrast to the nearby Dominguez Ruin at Dolores, where artiodactyl bones (mule deer, antelope, elk, and bighorn sheep) accounted for 62% of the total number of bones (Reed, 1979). Bone fragments from the MT3 House II midden are well-preserved and light in color, with sharp fracture edges, qualities indicative of bone that has been boiled or interred without flesh (White, 1992). Long bones, except those from very small mammals, are fractured as though for marrow extraction. The presence of many rodent jaw and small skull fragments in the faunal assemblage suggests that even small rodent skulls were smashed to extract the brains. In discussing the processing of animal bones by different ethnic groups, White (1992:359) comments that bone usage and processing intensity among the Kalam of New Guinea depended on "the extent that meat was available at the time and the extent to which the people were hungry. Whether these people bothered to smash long bones in order to extract the marrow depended on how much meat was available." The intensive processing of small long bones at 5MT3 House II during the Mancos period suggests that the Pueblo II inhabitants of 5MT3 had little access to large game and may have experienced a deficiency of animal protein in their diet.

Indications of possible starvation and/or societal disintegration at 5MT1/5MT3 are provided by two separate instances of presumed cannibalism that occurred at these sites during the Pueblo II time period, the first at 5MT1 during the early Mancos phase (about A.D. 950 to 1025) and the second at 5MT3 during the early to middle Mancos phase (about A.D. 1025 to 1050; Swedlund, 1969; Malville, 1989; White, 1992). Of the 32 fragmented human bone assemblages from the North American Southwest that have been identified as showing evidence of cannibalism (White, 1992; Turner and Turner, 1995), these are two of the earlier occurrences.

Yellow Jacket Canyon sites 5MT1 and 5MT3 are the only sites of the 32 listed by the Turners for which dental enamel hypoplasia has been examined in the resident population. My regional study of hypoplasia provides evidence that the Pueblo II occupants of Yellow Jacket Canyon sites 5MT1 and 5MT3 experienced greater biological disruption during early childhood than other ancestral Puebloans in the regional sample and that the level of chronic stress was significantly greater at 5MT1/5MT3 during the Pueblo II period than during the later Pueblo III period at these sites.

Excavation of 5MT5 in the future should help to clarify the relationship during Pueblo II times between the habitation sites 5MT1 and 5MT3 and the much larger community at 5MT5. If the entire Yellow Jacket Canyon area experienced episodes of locally severe drought and crop failure during the Pueblo II period, then all inhabitants of this area should have been equally stressed, and Pueblo II burials from 5MT5 should show the same high rate of dental enamel hypoplasia reported here for Pueblo II teeth from 5MT1/5MT3. On the other hand, lower rates of enamel disruption in 5MT5 dentition from the Pueblo II period would suggest social inequities and differential access to essential resources in the Yellow Jacket Canyon area and might explain some of the aberrant social behavior at 5MT1 and 5MT3 during the Mancos phase.

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